Thorium Fuel Cycle Activities in IAEA

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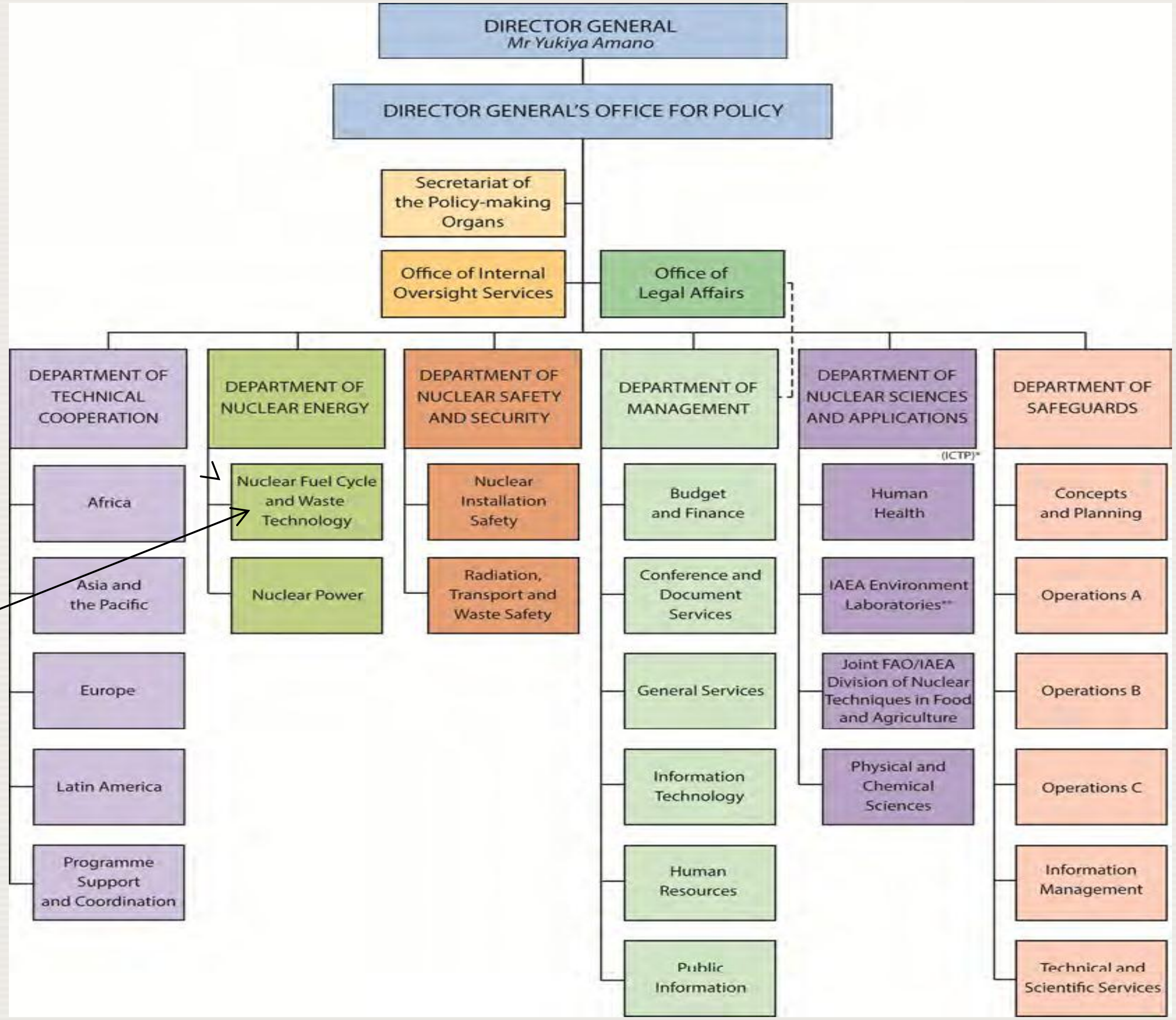
Department of Nuclear Energy

IAEA

International Atomic Energy Agency



Nuclear Fuel Cycle & Material Section

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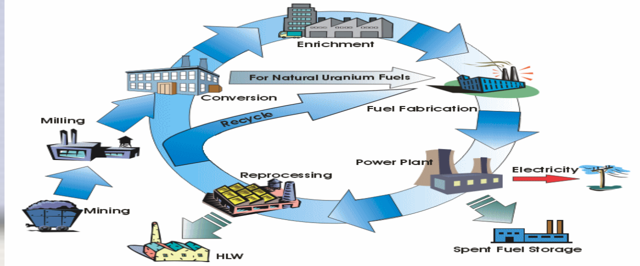

To promote information exchange on

1. Exploration, mining and processing of uranium and thorium ores
2. Design, manufacturing, and performance of conventional and advanced nuclear fuels
3. Management of spent fuel, including storage & treatment of spent fuel & recycling of plutonium, uranium and Minor Actinides (MA: Np, Am & Cm)

- **Technical co-operation**
- **Organizing Technical Meetings, Symposia and Coordinated Research Projects**
- **Preparation of state -of - the art Technical Documents**
- **Maintaining & updating Databases on Nuclear Fuels and Fuel Cycles**

Nuclear Fuel Cycle & Material Section

1. Uranium Group
2. Fuel Engineering
3. Spent Fuel Management
4. Advanced Fuels and Fuel Cycle

Advanced Nuclear Fuel Cycle : Objectives

To facilitate the development of

Innovative Nuclear Fuel Cycle

- Economically viable
- Efficient utilization of both fissile & fertile resources
- Safe and environment friendly
- Proliferation resistant
- Sustainable

IAEA Programme on

Advanced Nuclear Fuels and Fuel Cycle Options

- **Fuel and Fuel Cycles for Water Cooled Thermal & Liquid Metal Cooled Fast Reactors**
- **Reuse Options for Reprocessed Uranium**
- ***Thorium Fuel Cycles***
- **Advanced Technologies in Fuel Fabrication**
- **Partitioning and Transmutation (P&T)**

  Advanced Partitioning Methods

  MA bearing Fuels and Targets
- **Fuel and Fuel Cycles for HTR**
- **Fuel Cycle Options for SMRs with long core life**
-

Thorium Fuel Cycle ----- Major Incentives

- **Natural Abundance** of Thorium Resources

- 232Th is a **better fertile material** than 238U and produces **best fissile material** 233U in thermal reactors

- **Improved Thermo-physical Properties**, such as high melting pt., higher thermal conductivity and low co-efficient of thermal expansion compared to UO2 and MOX

- High Burn-up Capability

- Suitability for High Conversion Ratio Fuel Cycles

- Th based fuels have **Intrinsic proliferation resistance** characteristics due to the presence of 232U in 233U

- **Low radiotoxic waste** for 232Th-233U fuel cycle

Thorium Fuel Cycle ----- Challenges

● ThO_2 and ThO_2 based mixed oxide fuels, unlike UO_2 and $(UPu)O_2$ fuels, **do not dissolve easily in conc. HNO_3**

● **Automated & remote operation** in well shielded facility for 232Th-233U fuel fabrication.

● Three stream process of **separation of U, Pu and Th** from spent $(ThPu)O_2$ fuel is yet to be developed

● **Limited database and experience** of thorium fuels and fuel cycles compared to U and (UPu) fuels

Thorium Utilization in Experimental and Power Reactors

Thorium based fuels have been studied for their potential applications in almost all types of reactors including PWRs, BWRs, PHWRs, HTRs, FBRs and MSR, though on a small scale compared to U/U-Pu fuels

Amount of Thorium used in HTRs

HTR	Thorium (kg)
Dragon, UK	100
AVR, Germany	1360
Peach Bottom, USA	3500
THTR-300, Germany	6400
Fort St. Vrain, USA	26 500

Name	Country	Type	Power	Fuel	Operation period
AVR	Germany	HTGR, Experimental (Pebble bed reactor)	15 MW(e)	Th+^{235}U Driver Fuel, Coated fuel particles, Oxide & dicarbides	1967–1988
THTR-300	Germany	HTGR, Power (Pebble Type)	300 MW(e)	Th+^{235}U, Driver Fuel, Coated fuel particles, Oxide & dicarbides	1985–1989
Lingen	Germany	BWR Irradiation-testing	60 MW(e)	Test Fuel $(Th,Pu)O_2$ pellets	1968; terminated in 1973
Dragon (OECD-Euratom)	UK (also Sweden, Norway & Switzerland)	HTGR, Experimental (Pin-in-Block Design)	20 MWt	Th+^{235}U Driver Fuel, Coated fuel particles, Oxide & Dicarbides	1966–1973
Peach Bottom	USA	HTGR, Experimental (Prismatic Block)	40 MW(e)	Th+^{235}U Driver Fuel, Coated fuel particles, Oxide & dicarbides	1966–1972
Fort St Vrain	USA	HTGR, Power (Prismatic Block)	330 MW(e)	Th+^{235}U Driver Fuel, Coated fuel particles, Dicarbide	1976–1989
MSRE ORNL	USA	MSBR	7.5 MWt	^{233}U Molten Fluorides	1964–1969
BORAX-IV & Elk River Station	USA	BWR (Pin Assemblies)	2.4 MW(e); 24 MW(e)	Th+235U Driver Fuel Oxide Pellets	1963 - 1968
Shippingport	USA	LWBR PWR, (Pin Assemblies)	100 MW(e)	Th+^{233}U Driver Fuel, Oxide Pellets	1977–1982
Indian Point 1	USA	LWBR PWR, (Pin Assemblies)	285 MW(e)	Th+^{233}U Driver Fuel, Oxide Pellets	1962–1980
SUSPOP/KSTR KEMA	Netherlands	Aqueous Homogenous Suspension (Pin Assemblies)	1 MWt	Th+HEU, Oxide Pellets	1974–1977
NRX & NRU	Canada	MTR (Pin Assemblies)	20MW; 200MW (see)	Th+^{235}U, Test Fuel	1947 (NRX) + 1957 (NRU); Irradiation–testing of few fuel elements
CIRUS; DHRUVA; & KAMINI	India	MTR Thermal	40 MWt; 100 MWt; 30 kWt (low power, research)	Al+^{233}U Driver Fuel, 'J' rod of Th & ThO2, 'J' rod of ThO_2	1960-2010 (CIRUS); others in operation
KAPS 1 &2; KGS 1 & 2; RAPS 2, 3 & 4	India	PHWR, (Pin Assemblies)	220 MW(e)	ThO_2 Pellets (For neutron flux flattening of initial core after start-up)	1980 (RAPS 2) +; continuing in all new PHWRs
FBTR	India	LMFBR, (Pin Assemblies)	40 MWt	ThO_2 blanket	1985; in operation

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Thorium Fuel Cycle – Past & Present

1960s -- mid1980s

- R&D on Developing Thorium Fuels for Various Reactor Systems
- Motivation for near term deployment of thorium fuels dropped due to the **low uranium prices** and **weak sentiment toward nuclear power** in several parts of the world with the exception of a few countries like India

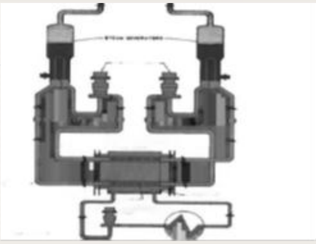
NOW

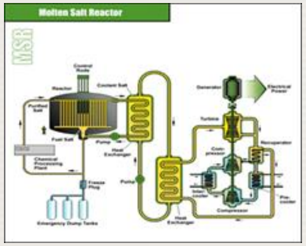
Motivation for Developing Thorium Technologies

Utilization of Large Energy Potential of Thorium Resources

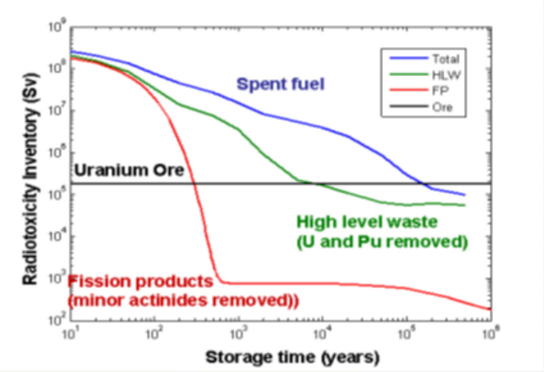
Trans-uranic Actinide (Pu and /or MAs) Consumption/Management

Proliferation Resistant Fuel Cycle





Self Sustaining Thorium Fuel Cycle Possible



Sustainable Development of Nuclear Energy is possible through the deployment of Thorium Fuel Cycle

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IAEA Technical Meetings (2011 – 2013)

- **World Thorium Resources** was held in Trivandrum, India in October, 2011
- **Fuel Integrity during Normal Operating and Accident Conditions in PHWR** was held in Bucharest, Romania in September, 2012
- **Advanced Fuel Cycles in PHWRs** was held in Mumbai, India in April, 2013
- **Thorium Resources and Provinces** was held in Vienna, Austria in September, 2013

CRP on Near Term and Promising Long Term Options for Deployment of Thorium Based Nuclear Energy (2012-2015)

CRP provides a platform for sharing of research results among participating Member States and the key focus is on the **development of strategies for deployment of Thorium based nuclear energy in NEAR, MEDIUM and LONG TERM timeframes & the identification of gaps in achieving the same.**

Results will be published in the form of a Document at the end of the project

Research Topics:

1. Reactor Systems: Concepts and designs that can effectively use thorium as a fuel.
2. Thorium based fuel fabrication / processing technologies
3. Thorium fuel performance
4. Spent thorium fuel reprocessing technologies
5. Economics of thorium fuel cycles
6. Identification of gaps that may affect commercial deployment
7. Strategies for deploying thorium fuel cycles in different time frames

Participating Member States

Canada, China, Czech Republic, Germany, Italy, Israel, India, Russian Federation and USA

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Investigation of Performance of Thorium Based Fuel Cycle in a PWR/FR Multi-tier System

Westinghouse, USA

Use of Thorium for Transuranic Waste Burning in a Multi-Tier Reactor System

This work aims at addressing the suitability and potential advantages of thorium-based nuclear system to perform full actinide recycle with transuranic isotopes burning. The system comprises current PWRs, reduced moderation water reactors (RMWRs) and liquid metal fast reactors.

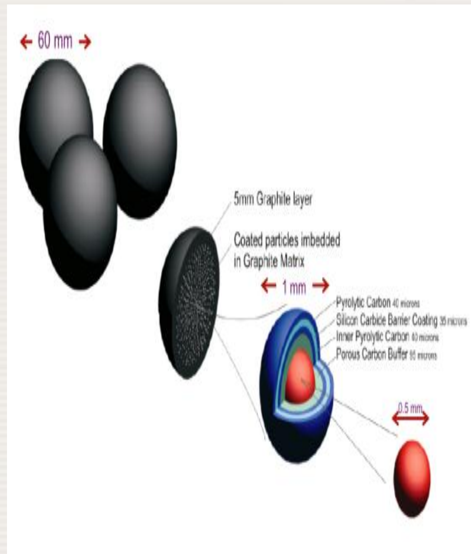
Preliminary neutronic analysis shows that thorium enables sustained TRU burning in all reactor systems analyzed: RMPWR, RMBWR and FRs

Evaluate the feasibility of utilizing the thermal fissile breeding capability of the Th-233U fuel cycle in HTR-PM

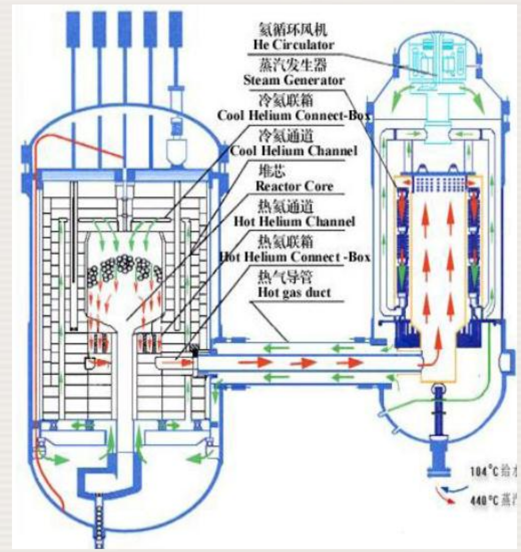
INET, TSINGHUA UNIV., China

Analysis of neutronics features of the Th-^{233}U fuel cycle in the equilibrium state of the HTR-PM

Pebbles with TRISO Coated Particles



HTR-10 to HTR-PM

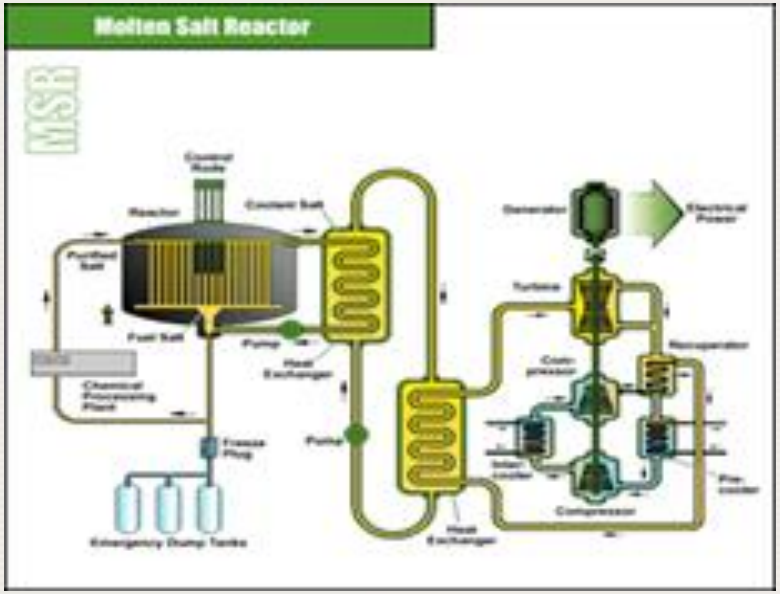


The investigation indicates that Th-U233 fuel cycle in HTR-PM is feasible and realistic.

Deployment of Thorium in Molten Salt Reactor Systems

NRI, Czech Republic

R&D aspects necessary for future deployment of thorium fuel in Molten Salt Reactor



Nuclear Research Institute is involved in MSR reactor physics & neutronics studies and in experimental development of fluoride pyrochemical separation processes devoted to the MSR Th-U fuel cycle including on-line reprocessing, reactor chemistry and structural material development and compatibility studies

AECL, Canada

R & D at AECL focused on key technology areas including fabrication technology, irradiation testing and post-irradiation examination, materials properties characterization, modelling of thoria fuel behaviour, fuel safety and licensing, thorium reactor physics, waste management, fuel recycling etc.

Fluoride Volatility as a method to separate Uranium from used Thoria-based fuel

A lab scale apparatus has been set up to perform fluoride volatility experiments on (Th,U)O_2 fuel and simulated irradiated fuel. Thermodynamic modelling software will be used to model the thermochemical behaviour of the Th-U-O-F system at various temperatures. The software will be used to predict the stable equilibrium chemical species present at given experimental conditions so that process parameters can be optimized.

The research work involves the preliminary design study for both PWR and BWR systems with self-sustainable Th fuel cycle and outlining the main design challenges. Among the challenges, the basic tradeoff between achievable power density and breeding performance.

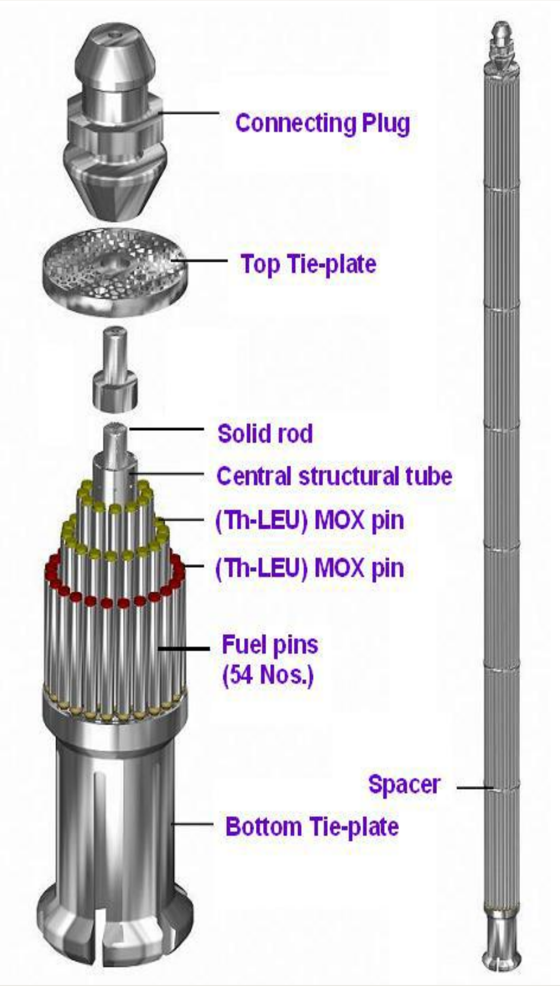
One of the project constraints is that the **considered LWR designs** should have conventional reactivity control means (no variable fuel geometry control similar to LWBR Shippingport reactor) and can be potentially retrofitable into current generation of LWRs.

Work programme includes:

1. Concepts for utilization of thorium in HWRs including a comparison of different fuel cycles that could be adopted for these reactor systems

2. Analytical and experimental activities for (Th-Pu) MOX and (Th-LEU) MOX type fuels in the area of fabrication, performance modelling, out-of –pile properties evaluation, in-pile irradiation and PIE

3. Studies for open fuel cycle such as spent fuel behaviour during extended storage, characterization of spent fuel for waste management



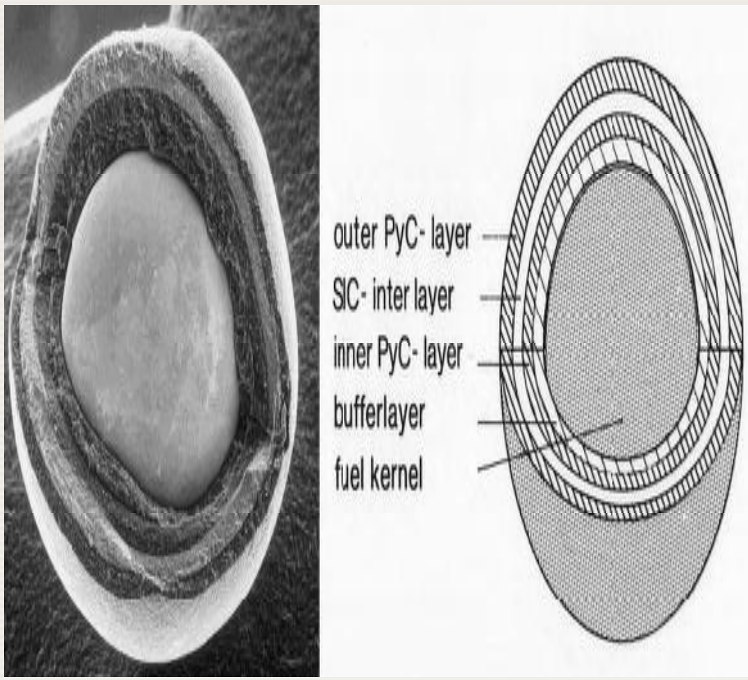
Three type of Fast Reactors considered for studies:

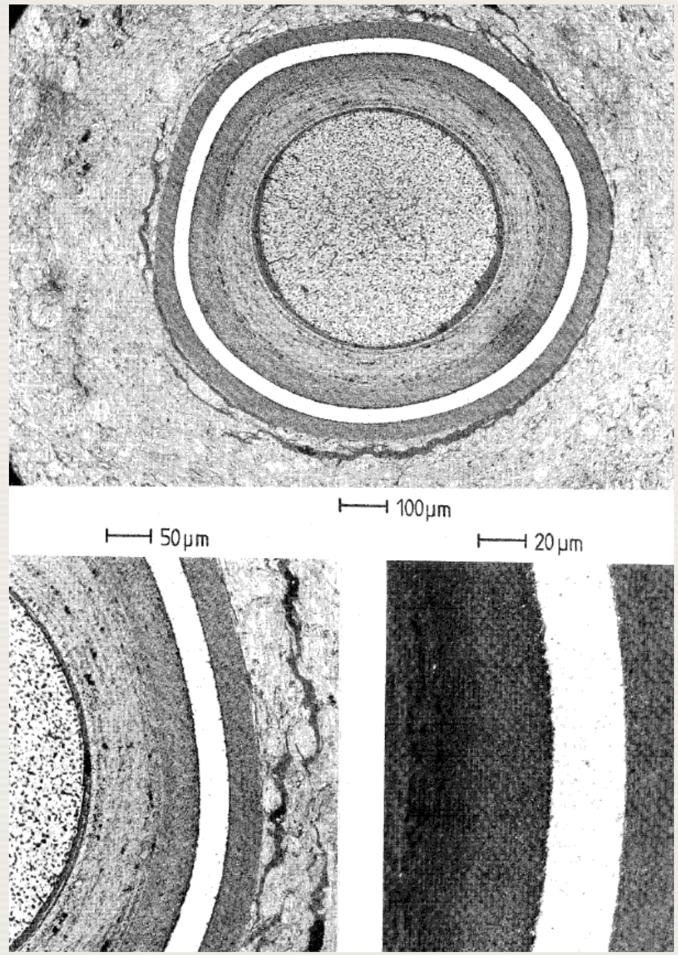
1. TRU-burner sodium cooled FR (ARR)
2. Iso-breeder lead cooled FR (ELSY)
3. Fast Spectrum Molten Salt Reactor (MSFR)

Compilation and Analysis of Available Results on Thorium Coated Particle Performance in Manufacture, in Material Test Reactors and in the AVR, and during Accident Condition Tests

ARGE KT, Germany

Ceramographic sections of $(Th,U)O_2$ TRISO particles from AVR fuel element irradiated to 8.6% FIMA and heated for 92 hours at 1800° C.





The ceramography showed no evidence of corrosion in the SiC layer or any detrimental effects due to the 92 h exposure at temperatures of 1800ºC consistent with the good results in gas release

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Design of a PWR core fully loaded with Th-MOX

Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany

1. Steady-state and accident analysis of 100% TOX PWR core will be performed.

2. 100% TOX PWR core behavior under steady-state and accident conditions will be compared with that of the typical U-fuel PWR and 100% MOX PWR cores.

3. Conclusions regarding neutronic feasibility of 100% TOX PWR will be drawn.

2.

1. Selection of the principal dimensions of the reactor and preliminary determination of fertile and fissile material content in the supercritical core taking into account the parameters such as fuel rods, FAs, control rods, blankets, coolant flow rates and its thermal properties etc. The choice has to be based on the condition of maximum breeding.

2. Determination of basic fuel characteristics namely, initial charge of fissile and fertile materials, annual charge and discharge with calculation of isotopic vectors and determination of fresh and spent fuel radiotoxicity.

New CRP on Reliability of High power, Extended burn up and Advanced PHWR Fuels (2013-2017)

The current generation of PHWR fuels has been highly optimized for the traditional PHWR fuel cycles. However both evolutionary and revolutionary developments in the fuel cycle are putting new demands of fuel designs

This CRP is intended to encourage the development and sharing of research work on resolving these challenges

Fuel performance issues arising from increased power and burnup in PHWR fuels include:

- Increased release of gaseous and volatile fission products
- Pellet-clad interaction
- Degradation of fuel thermal properties
- Burnup dependent thermo-mechanical properties
- Clad corrosion
- Stress corrosion cracking

Research Topics

1. Fuel Concepts for High Burnup (Design, Material & Fabrication)
2. Life Limiting Aspects of Extended Burnup & Advanced Fuels including Accident Tolerant Fuel
3. Advanced Fuels Leading to Improved Safety Margins

http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/advanced-fuel-cycles-crp-phwr-fuel-2013.html

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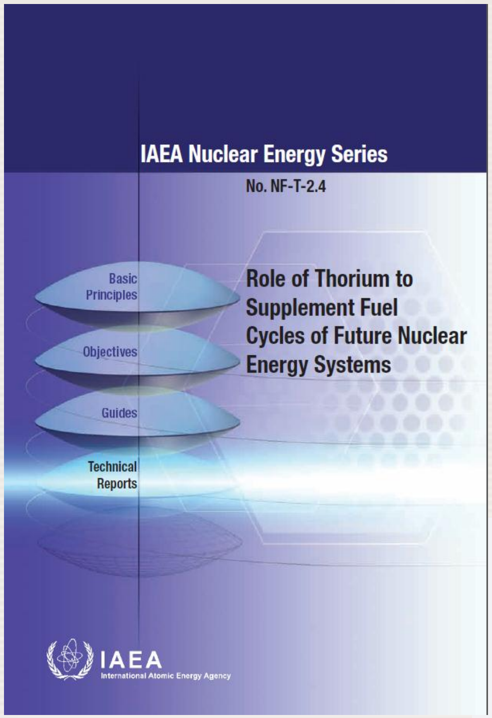
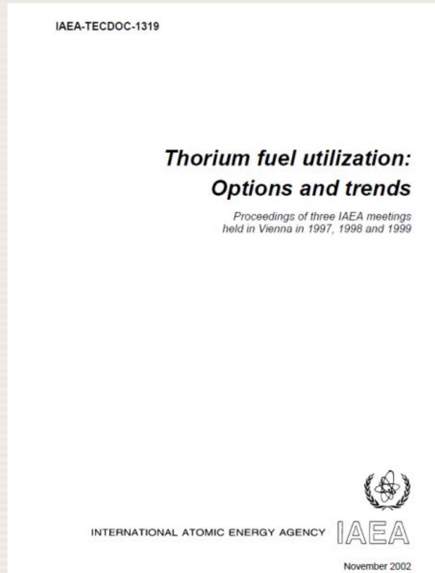
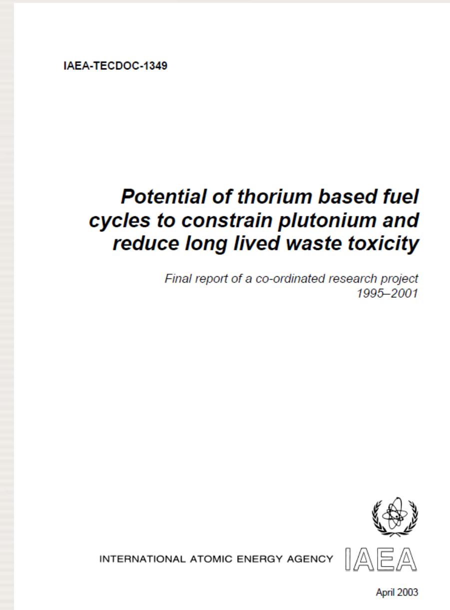
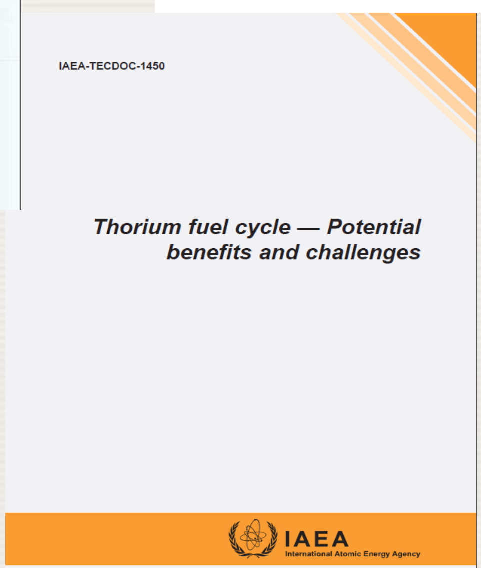
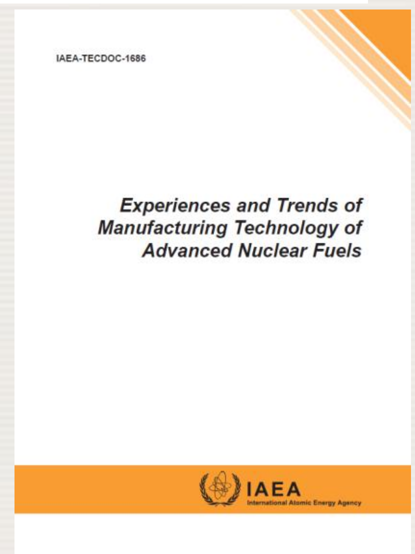
IAEA Publications on Thorium Fuel Cycle











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Document on World's Thorium Resources (to be published in 2014)

WORLD THORIUM OCCURRENCES,
DEPOSITS AND RESOURCES

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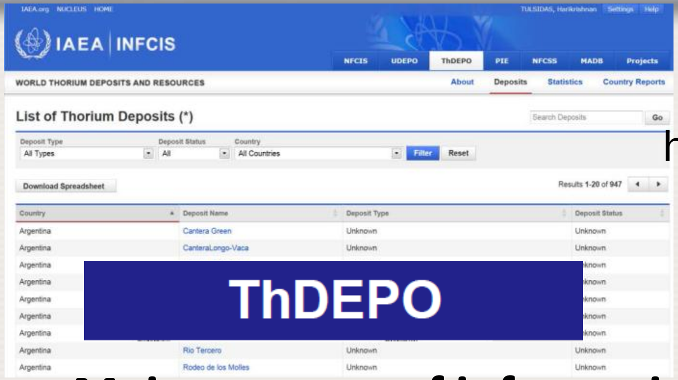
Draft document under preparation



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- IAEA Techn. Meetings: Trivandrum, Kerala, India, 17-21 Oct. 2011 & Vienna, Sept. 24-27, 2013.

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Summaries

- Use of Thorium based fuels was demonstrated in almost all types of reactors during the period between 1960s – mid 1980s

- Large resources of thorium along with favourable waste management and intrinsic proliferation characteristics of Thorium - Uranium fuel cycle has the potential for the Sustainable Development of Nuclear Energy

- Technological challenges for remote and automated processes even for the Front End of Thorium – Uranium Fuel Cycle in well shielded facilities

- Global Attitudes towards deployment of Thorium Fuel Cycle are fast changing.

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